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Bowers, III et al.

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(54) **DETECTING FAULTY COLLECTION OF VIBRATION DATA**

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Related U.S. Application Data

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G01N 29/04 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01N 29/4463*** (2013.01); ***G01N 29/04*** (2013.01); ***G01N 29/14*** (2013.01); ***G01N 29/40*** (2013.01); ***G01N 29/44*** (2013.01); ***G01N 29/449*** (2013.01); ***G01N 29/4427*** (2013.01); ***G01N 29/4445*** (2013.01); ***G01N 29/46*** (2013.01); ***G01N 29/48*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC .. G01N 29/4463; G01N 29/04; G01N 29/449; G01N 29/4445; G01N 29/4427; G01N 29/14; G01N 29/46; G01N 29/40; G01N 2291/023; G01N 2291/0258; G01N 2291/015; G01N 29/44; G01N 29/4409; G01N 29/48; G01M 99/005; G01M 13/028; G01M 13/045; G01M 15/12; G01M 15/14; G01H 13/00; G01H 17/00; G05B 19/04
See application file for complete search history.

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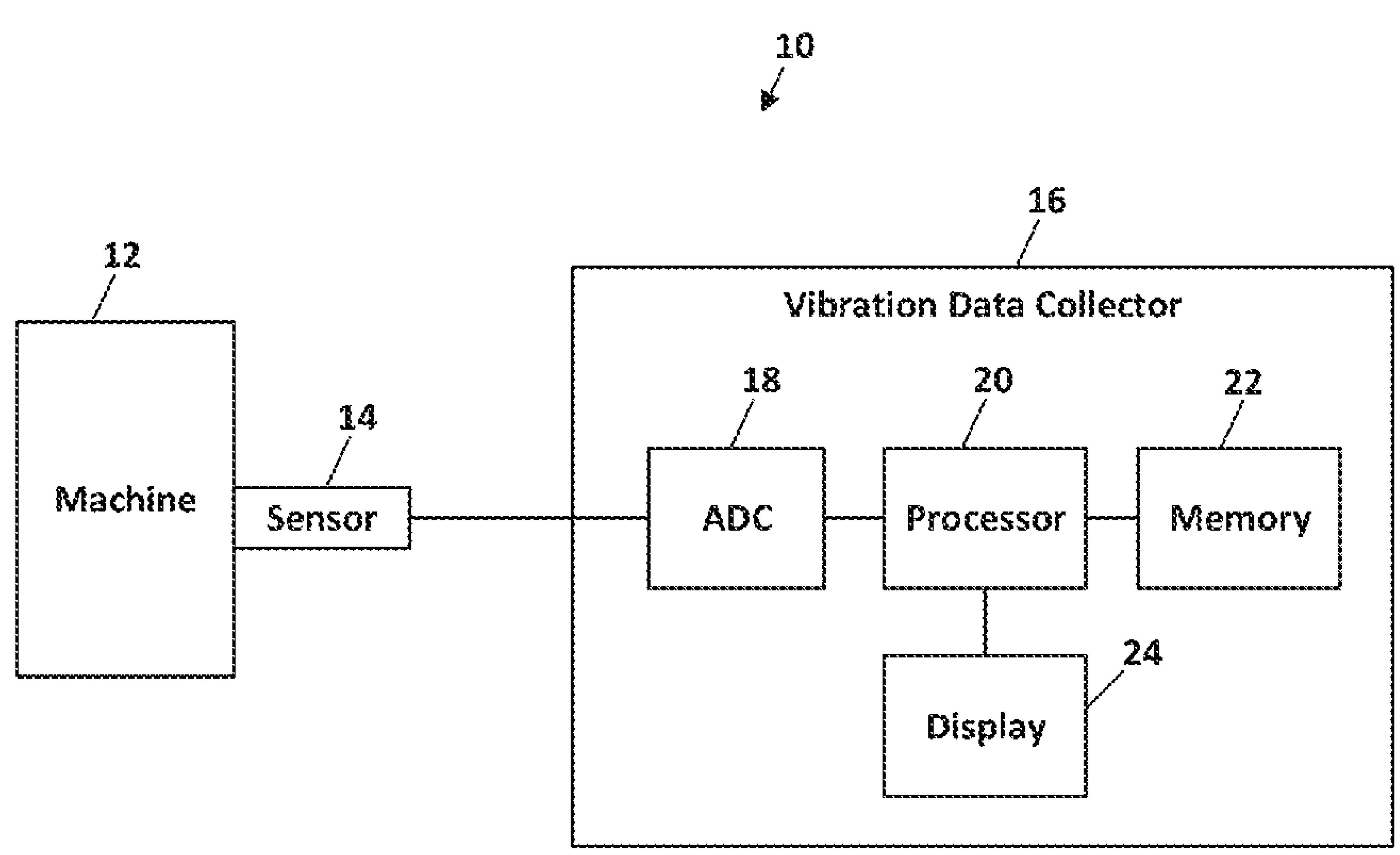
(57) **ABSTRACT**

Vibration data indicative of the health of a machine is collected using a vibration sensor connected to a portable vibration data collector. After the vibration sensor has been attached to a measurement point on the machine, vibration data is collected over a measurement time period having a begin time and an end time, and the vibration data is stored in memory of the portable vibration data collector. First and second average amplitudes of the vibration data collected during first and second time windows in the measurement time period are determined. The slope of the vibration data is calculated based on the ratio of the amplitude difference between the first and second average amplitudes and the time difference between the first and second time windows. The vibration data is either retained in the memory or discarded based on the comparison of the slope to a threshold level.

8 Claims, 4 Drawing Sheets



(51) **Int. Cl.**

G01N 29/14	(2006.01)
G01N 29/46	(2006.01)
G01N 29/40	(2006.01)
G01N 29/48	(2006.01)

(52) **U.S. Cl.**

CPC . *G01N 2291/015* (2013.01); *G01N 2291/023* (2013.01); *G01N 2291/0258* (2013.01)

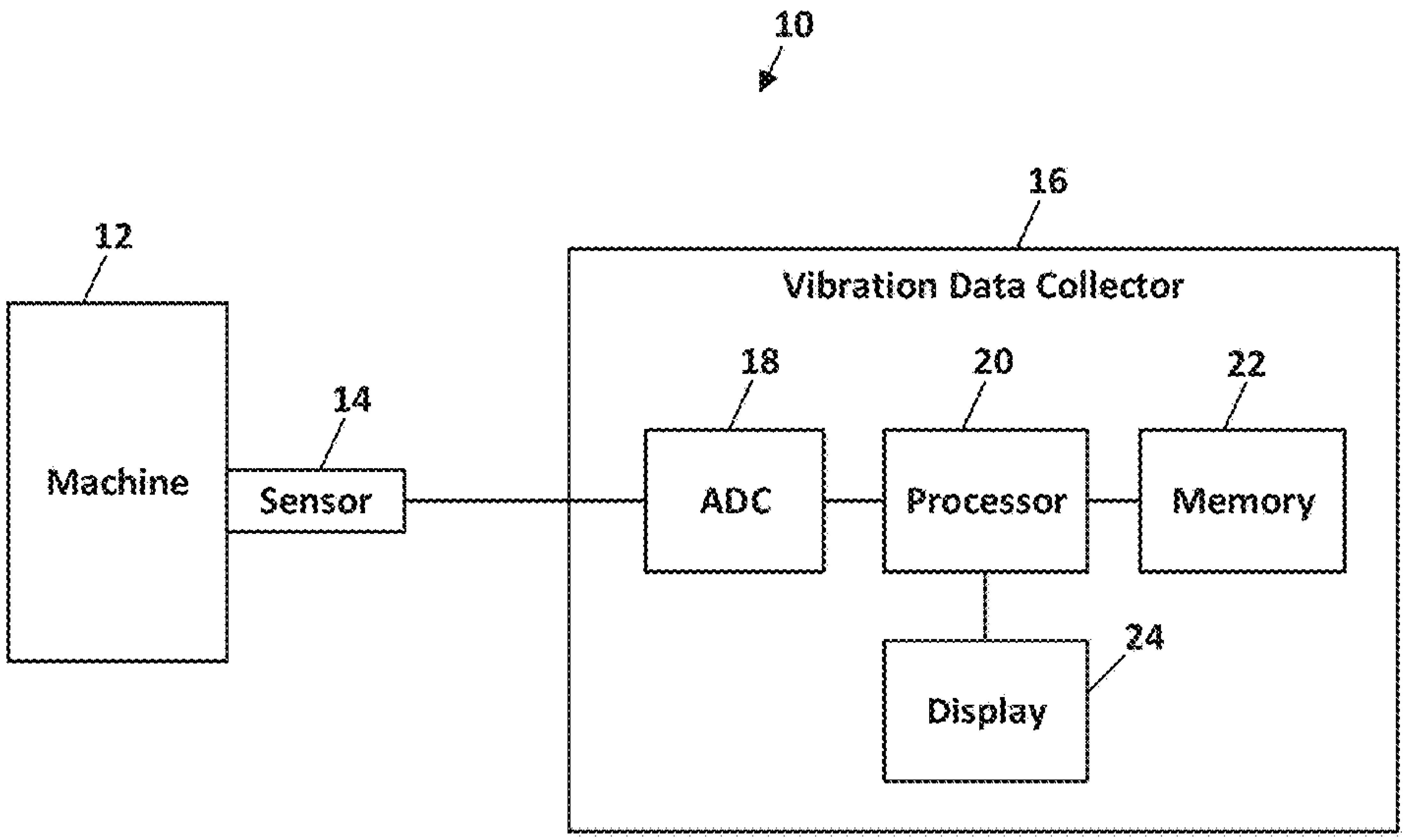

10
16
Vibration Data Collector
12
Machine
14
Sensor
18
ADC
20
Processor
22
Memory
24
Display

FIG. 1

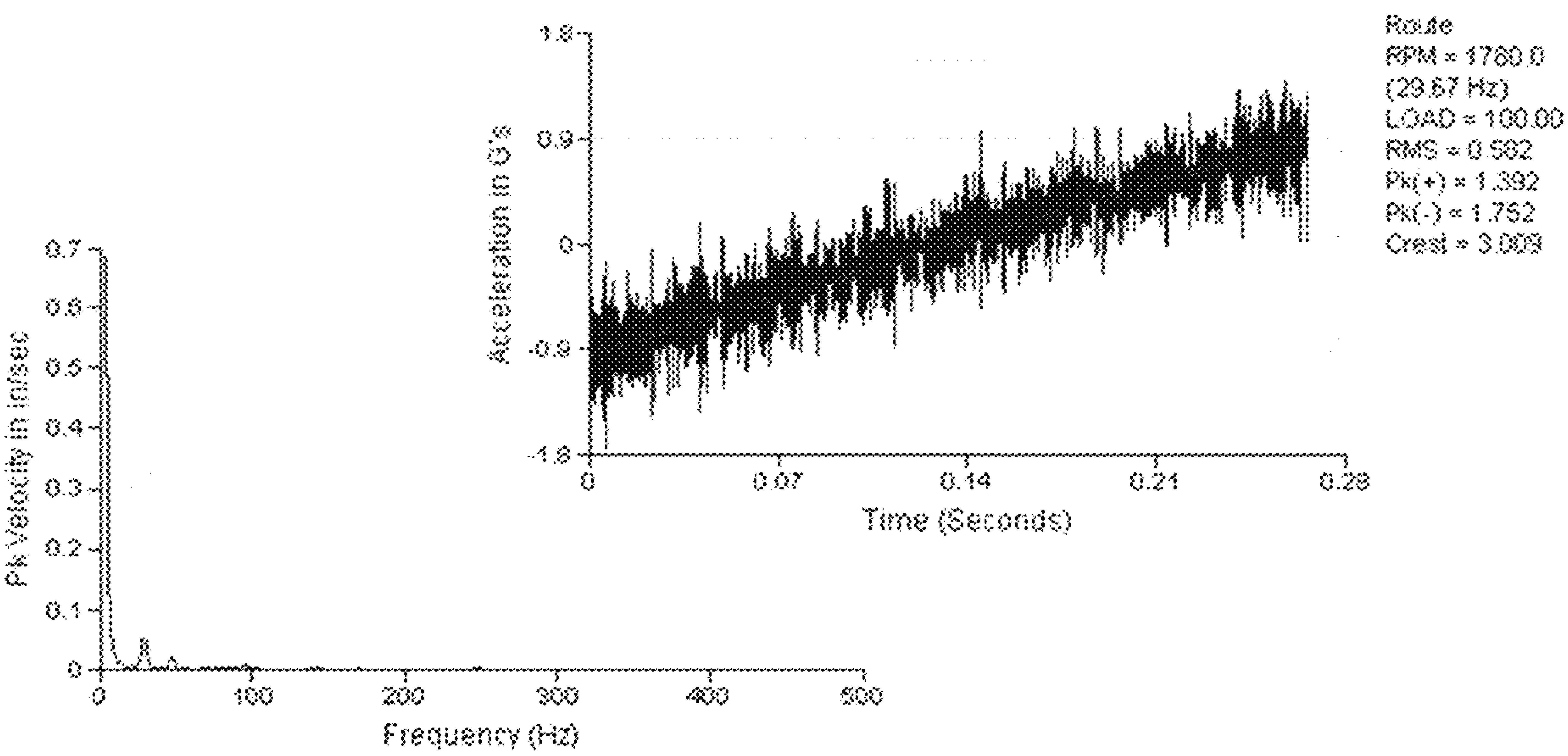

Route
RPM = 1780.0
(29.67 Hz)
LOAD = 100.00
RMS = 0.582
Pk(+) = 1.392
Pk(-) = 1.752
Crest = 3.009
Acceleration in G's
Time (Seconds)
Pk Velocity in in/sec
Frequency (Hz)

FIG. 2

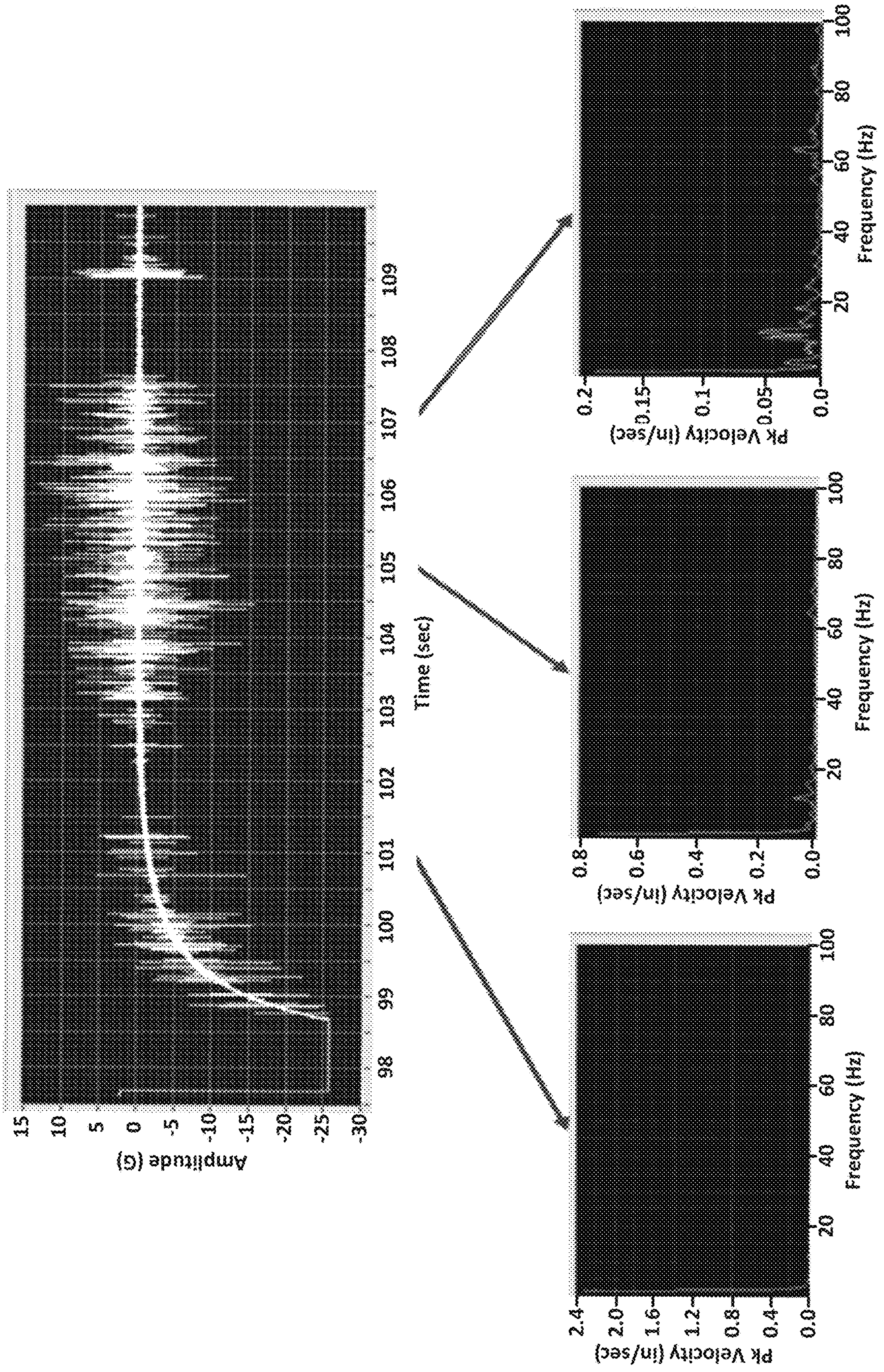

Amplitude (G)
15 10 5 0 -5 -10 -15 -20 -25 -30
Time (sec)
98 99 100 101 102 103 104 105 106 107 108 109
Pk Velocity (in/sec)
0.2 0.15 0.1 0.05 0.0
Frequency (Hz)
20 40 60 80 100
Pk Velocity (in/sec)
0.8 0.6 0.4 0.2 0.0
Frequency (Hz)
20 40 60 80 100
Pk Velocity (in/sec)
2.4 2.0 1.6 1.2 0.8 0.4 0.0
Frequency (Hz)
20 40 60 80 100

FIG. 3

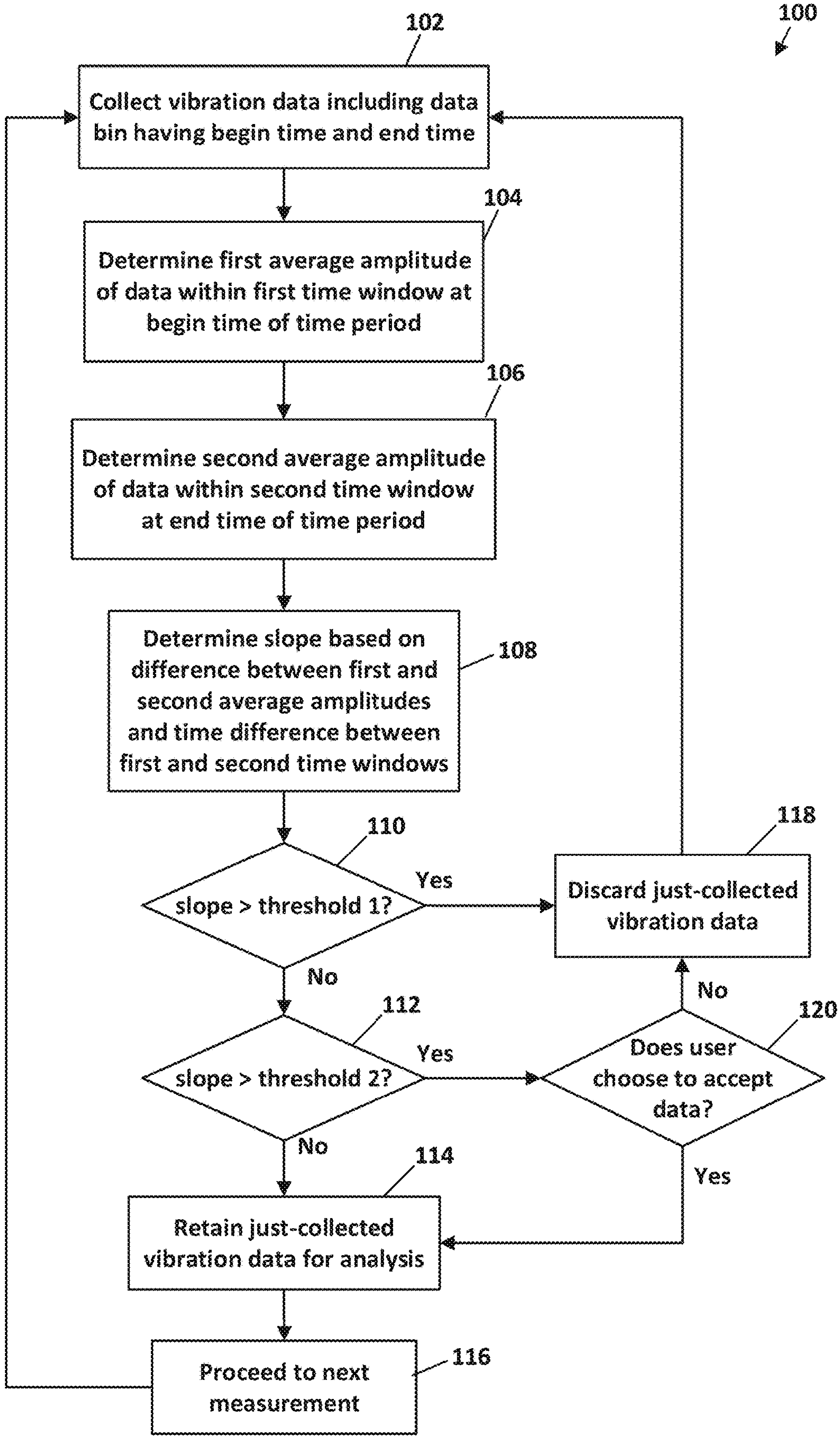

100
102
Collect vibration data including data bin having begin time and end time
104
Determine first average amplitude of data within first time window at begin time of time period
106
Determine second average amplitude of data within second time window at end time of time period
108
Determine slope based on difference between first and second average amplitudes and time difference between first and second time windows
110
slope > threshold 1?
Yes
No
118
Discard just-collected vibration data
112
slope > threshold 2?
Yes
No
120
Does user choose to accept data?
No
Yes
114
Retain just-collected vibration data for analysis
116
Proceed to next measurement

FIG. 4

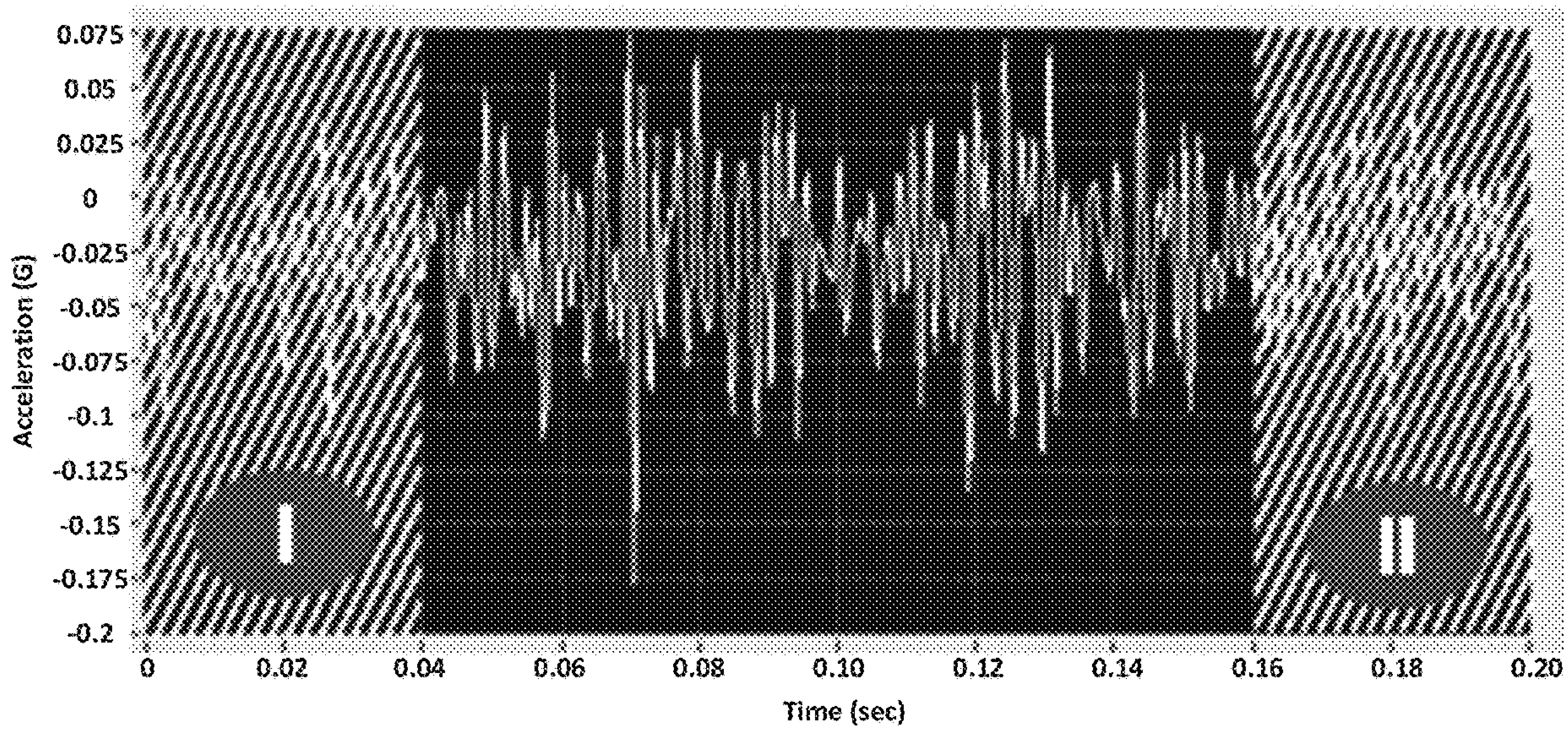

0.075
0.05
0.025
0
-0.025
-0.05
-0.075
-0.1
-0.125
-0.15
-0.175
-0.2
Acceleration (G)
I
II
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
Time (sec)

FIG. 5A

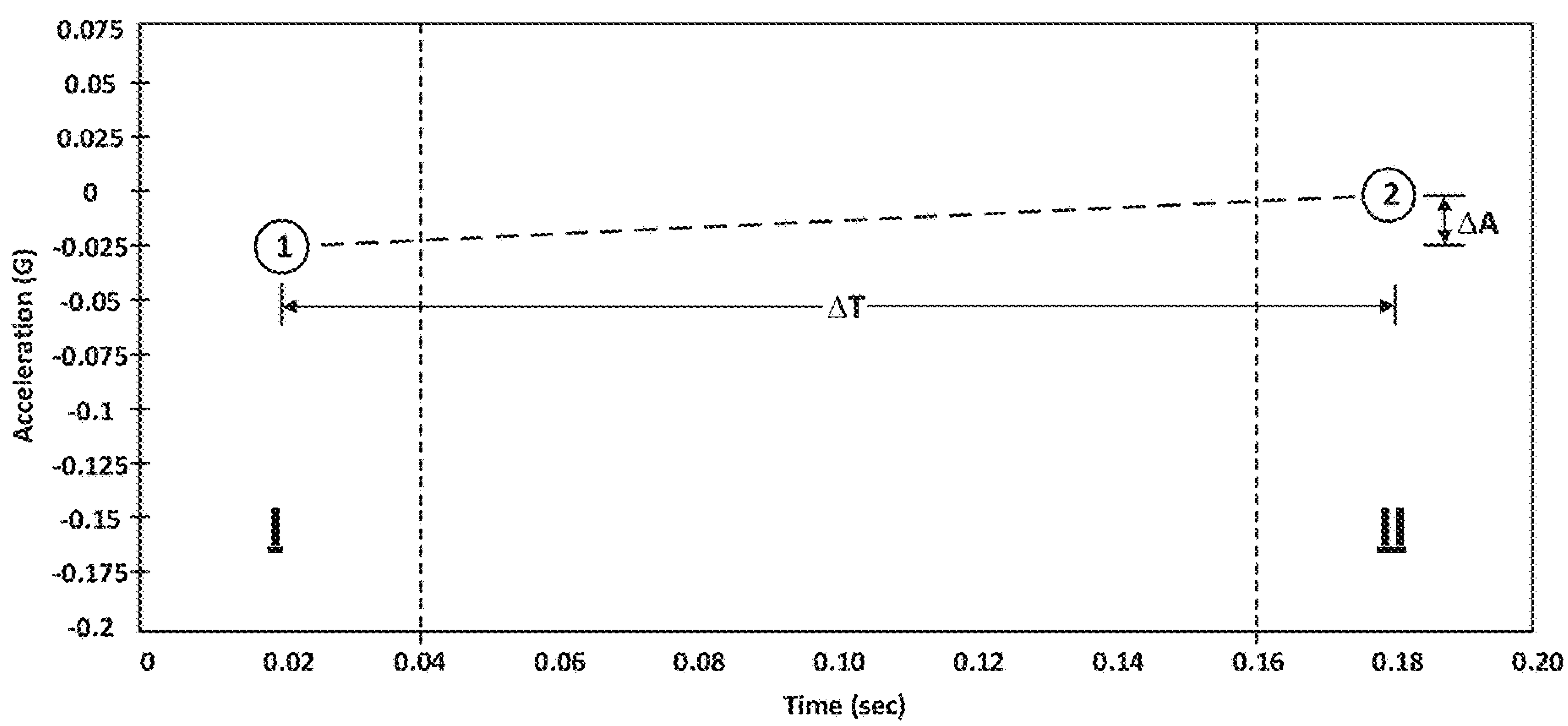

0.075
0.05
0.025
0
-0.025
-0.05
-0.075
-0.1
-0.125
-0.15
-0.175
-0.2
Acceleration (G)
1
2
ΔA
ΔT
I
II
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
Time (sec)

FIG. 5B

DETECTING FAULTY COLLECTION OF VIBRATION DATA

RELATED APPLICATIONS

This application claims priority as a divisional to U.S. application Ser. No. 15/420,933, titled Detecting Faulty Collection of Vibration Data, filed Jan. 31, 2017, the entire contents of which are incorporated herein by reference.

FIELD

This invention relates to the field of machine vibration monitoring. More particularly, this invention relates to a system for detecting and discarding undesirable vibration data prior to analysis of the data.

BACKGROUND

In industrial facilities that utilize machines having rotating components, vibration generated by the machines may be monitored to detect abnormal conditions that could lead to machine failure. Machine vibration may be monitored using a handheld portable vibration data collector carried by a technician from one machine to another along a machine data collection route. Such vibration data collectors typically employ a vibration sensor, such as a piezoelectric sensor, that generates an electrical signal indicative of vibration levels of the machine. The machine data is often stored in memory in the data collector as the technician proceeds along the route, and is uploaded to a data analysis computer after completion of the route. A data analyst may then use vibration data analysis software running on the data analysis computer that processes the vibration data to provide information to the analyst regarding operational performance of the machines along the route.

Sometimes the vibration data collected along the route is unusable due to problems in the way the data was collected. In some instances, the problems are due to electrical transients in the sensor signal or exposure of the sensor to mechanical shock immediately prior to the collection of the data.

What is needed is a method for detecting that vibration data is undesirable for data analysis purposes as the data is collected, and discarding the undesirable data prior to data analysis.

SUMMARY

The above and other needs are met by a method for collecting vibration data indicative of the health of a machine using a vibration sensor connected to a portable vibration data collector. A preferred embodiment of the method includes the following steps:

(a) attaching the vibration sensor to a measurement point on the machine;

(b) collecting vibration data over a measurement time period having a begin time and an end time;

(c) storing the vibration data in memory of the portable vibration data collector;

(d) determining a first average amplitude of the vibration data collected during a first time window in the measurement time period;

(e) determining a second average amplitude of the vibration data collected during a second time window in the measurement time period;

(f) determining the slope of the vibration data based on the ratio of the amplitude difference between the first and second average amplitudes and the time difference between the first and second time windows; and

(g) retaining or discarding the vibration data collected in step (b) based on comparison of the slope to one or more threshold levels.

In some embodiments, step (g) includes deleting the vibration data collected in step (b) from the memory if the slope is greater than a first threshold level.

In some embodiments, steps (b) through (g) are repeated until the slope is less than the first threshold level, at which point the vibration data collected in step (b) is retained in the memory.

In some embodiments, step (g) includes:

(g1) prompting a user of the portable vibration data collector to choose to retain or discard the vibration data collected in step (b) if the slope is less than a first threshold level and greater than a second threshold level, wherein the second threshold level is less than the first threshold level; and

(g2) retaining or discarding the vibration data collected in step (b) based on the choice of the user.

In some embodiments, the prompting of step (g1) is accomplished by a visual prompt on a display screen of the portable vibration data collector.

In some embodiments, the first time window begins at the begin time of the measurement time period and the second time window ends at the end time of the measurement time period.

In some embodiments, the time difference between the first and second time windows is determined to be the difference in time between the mean time of the first time window and the mean time of the second time window.

In some embodiments, the widths of the first and second time windows are no greater than one half of the measurement time period.

In another aspect, embodiments of the invention provide a method for collecting vibration data indicative of the health of a plurality of machines along a measurement route using a vibration sensor connected to a portable vibration data collector. This method includes:

(a) attaching the vibration sensor to a measurement point on a machine on the measurement route;

(b) collecting vibration data over a measurement time period having a begin time and an end time;

(c) storing the vibration data in memory of the portable vibration data collector;

(d) determining a first average amplitude of the vibration data collected during a first time window in the measurement time period;

(e) determining a second average amplitude of the vibration data collected during a second time window in the measurement time period;

(f) determining the slope of the vibration data based on the ratio of the amplitude difference between the first and second average amplitudes and the time difference between the first and second time windows;

(g) determining to retain or discard the vibration data collected in step (b) based on comparison of the slope to one or more threshold levels;

(h) if it is determined in step (g) to discard the vibration data, repeating steps (b) through (g) until it is determined in step (g) to retain the vibration data;

(i) proceeding to a next measurement point in the measurement route; and

(j) repeating steps (a) through (i) until vibration data has been collected and retained for all measurement points in the measurement route.

In some embodiments, step (g) includes deleting the vibration data collected in step (b) from the memory if the slope is greater than a first threshold level,

In some embodiments, the method includes performing step (h) until the slope is less than the first threshold level, at which point the vibration data collected in step (b) is retained in the memory.

In yet another aspect, embodiments of the invention are directed to a portable vibration data collector for collecting vibration data indicative of the health of a machine. The portable vibration data collector includes a vibration sensor, an analog-to-digital converter, memory, and a processing device. The vibration sensor attaches to a measurement point on the machine and generates vibration signals based on vibration of the machine during a measurement time period having a begin time and an end time. The analog-to-digital converter converts the vibration signals to digital vibration data, and the memory stores the vibration data. The processing device operates on the vibration data based on execution of software commands that:

- determine a first average amplitude of the vibration data collected during a first time window in the measurement time period;
- determine a second average amplitude of the vibration data collected during a second time window in the measurement time period;
- determine the slope of the vibration data based on the ratio of the amplitude difference between the first and second average amplitudes and the time difference between the first and second time windows; and
- retain the vibration data in the memory or delete the vibration data from the memory based on comparison of the slope to one or more threshold levels.

In some embodiments, the processing device deletes the vibration data from the memory if the slope is greater than a first threshold level.

In some embodiments, the processing device continues the collection of vibration data at the measurement point until the slope is less than the first threshold level, at which point the collected vibration data is retained in the memory.

In some embodiments, the execution of commands by the processing device:

- generates a message on a display device that prompts a user of the portable vibration data collector to choose to retain or discard the vibration data if the slope is less than a first threshold level and greater than a second threshold level, wherein the second threshold level is less than the first threshold level; and
- causes the vibration data to be retained in the memory or deleted from the memory based on the choice of the user.

BRIEF DESCRIPTION OF THE DRAWINGS

Other embodiments of the invention will become apparent by reference to the detailed description in conjunction with the figures, wherein elements are not to scale so as to more clearly show the details, wherein like reference numbers indicate like elements throughout the several views, and wherein:

FIG. **1** depicts an apparatus for collecting machine vibration data according to an embodiment of the invention;

FIGS. **2** and **3** depict time domain and frequency domain plots of machine vibration data collected using the apparatus of FIG. **1**;

FIG. **4** depicts a method for processing machine vibration data to detect and discard undesirable data; and

FIGS. **5**A and **5**B depict time domain plots of machine vibration data processed according to the method of FIG. **4**.

DETAILED DESCRIPTION

Embodiments described herein are directed to eliminating a noise problem referred to as "ski-slope noise" that may be observed in machine vibration data collected on a machine in a data collection route using a portable vibration data collection system, such as the exemplary system **10** depicted in FIG. **1**. The system **10** includes a sensor **14** that a user attaches to a machine **12** to be tested along the route. In a preferred embodiment, the sensor **14** is a piezoelectric sensor that generates an electrical voltage signal that is indicative of the level of vibration generated by the machine **12**. The sensor **14** is electrically connected to a portable handheld vibration data collector **16**, such as a CSI 2140 Machinery Health Analyzer. The data collector **16** includes an analog-to-digital converter (ADC) **18** that converts the analog voltage signal from the sensor **14** into digital vibration data. A processor **20** in the data collector **16** receives the vibration data and processes it according to methods described herein, in which the data is either discarded or retained in memory **22**.

FIG. **2** illustrates the "ski-slope noise" problem. In the lower left portion of FIG. **2** is an exemplary peak velocity frequency spectrum derived from data collected on a route using the system **10** depicted in FIG. **1**. The large spectral amplitude at very low frequency, which has a steep downward slope toward higher frequency, is referred to as a "ski-slope." In this example, the peak is not so large in amplitude that it completely overshadows all other spectra features, although it is still more than a factor of ten larger than any other spectral peak. The upper right portion of FIG. **2** depicts a time waveform of the vibration data from which the frequency spectrum is derived. One of the most striking things about the waveform is the obvious slope in acceleration amplitude over time.

There are two common events that induce the sensor **14** to generate a vibration signal having the characteristics depicted in FIG. **2**. One event is an electrical transient generated in the sensor circuitry when the sensor **14** is initially connected to its power source. The other event is the subjection of the sensor to a large mechanical shock, such as may occur in the process of placing the sensor on the machine **12** to be monitored.

FIG. **3** depicts data collected from an accelerometer using a digital recorder, where the accelerometer had been disconnected from the recorder, thereby interrupting its electrical power, and then reconnected to the recorder. The upper image in FIG. **3** shows the raw vibration waveform signal from the sensor as digitized by the digital recorder. As the upper image indicates, the raw waveform signal recovers from the reconnection event that occurs at an elapsed time of about 98.7 seconds. The three lower images in FIG. **3** are spectra computed from the upper waveform beginning at 2.3 seconds, 6.3 seconds, and 8.3 seconds after the reconnection event. As the three spectra indicate, the amplitude of the ski-slope feature decreases by more than a factor of ten over this six-second time range. Although there is still a prominent ski-slope peak in the 8.3-second spectrum, the desired vibration signal is readily visible.

In embodiments described herein, the processor **20** of the vibration data collector **16** computes the slope of the vibration time waveform signal in real time. Since the computed slope correlates to the amplitude of the ski-slope feature in the frequency spectrum, the computed slope is an indicator of the severity of the ski-slope problem. Because the slope can be computed in real time, data that exhibits a severe ski-slope problem can be discarded in real time to avoid using memory space to store undesirable data.

FIG. **4** depicts an exemplary method **100** executed by the processor **20** to detect and discard undesirable vibration data collected on a machine data collection route. At a starting point in the route, the user attaches the sensor **14** to a measurement location on the machine **12** and uses the data collector **16** to collect a bin of vibration data over some time period (step **102**). An exemplary bin of vibration data spanning an 0.2 second time period is depicted in FIG. **5**A. It should be appreciated that the invention is not limited to any particular length of time for the initial data collection. In the example of FIG. **5**A, a time period of 0.2 seconds is long enough to contain several cycles of the machine running speed for a machine driven by a two-pole AC motor. This exemplary time period is also typically short enough that it can be sampled and computations completed in a shorter time than required to do a full vibration data collection at any particular point on the route.

In a preferred embodiment, the processor **20** calculates the mean amplitude of the measured vibration signal within a first time window near the start of the data collection time period (step **104**). This first time window is indicated by the cross-hatched section I in FIG. **5**A, which may be as wide as one-half the total width of the data collection time period. In the current example, the width of the first time window is 0.04 seconds. The processor **20** also calculates the mean amplitude of the measured vibration signal within a second time window near the end of the data collection time period (step **106**). This second time window is indicated by the cross-hatched section II in FIG. **5**A, which may be as wide as one-half the total width of the data collection time period. In the current example, the width of the second time window is also 0.04 seconds. In a preferred embodiment, the amplitudes of all data points of the waveform within each time window are averaged to determine a single mean amplitude value for each window.

The mean amplitude value for the first time window is represented by circle **1** in FIG. **5**B. The mean amplitude value for the second time window is represented by circle **2** in FIG. **5**B. The difference in amplitude between the two mean amplitude values is represented as ΔA and the mean time difference between the first and second time windows is represented as ΔT in FIG. **5**B. The processor **20** calculates a simple slope S according to:

$$S=\Delta A\div\Delta T \text{ (step 108).}$$

In the example of FIGS. **5**A-**5**B, ΔA=0.025 g and ΔT=0.16 sec. and

$$S=0.025\div0.16=0.15625 \text{ g/sec.}$$

The slope S is then compared to a stored first threshold value (step **110**). If the slope S is greater than the first threshold value, the data collected at step **102** is discarded by deleting it from the memory **22** (step **118**). If the slope S is not greater than the first predetermined threshold value, the slope S compared to a stored second threshold value that is less than the first threshold value (step **112**). If the slope S is not greater than the second threshold value, the data is retained in memory in association with an identification of the current measurement route point (step **114**). If the slope S is greater than the second threshold value, a message is displayed on the display device **24** of the data collector **16** prompting the user to either accept the data as good enough or reject the data as undesirable (step **120**). If the user accepts the data, the data is retained in memory in association with the identification of the current measurement route point (step **114**). If the user chooses to reject the data, the data collected at step **102** is discarded by deleting it from the memory **22** (step **118**).

After the user proceeds to the next data collection point in the route (step **116**), and process steps are repeated until acceptable data has been collected at all measurement points in the route. Data that remains in the memory **22** after step **114** will be available for consideration by a data analyst after completion of the route.

The foregoing description of preferred embodiments for this invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise form disclosed. Obvious modifications or variations are possible in light of the above teachings. The embodiments are chosen and described in an effort to provide the best illustrations of the principles of the invention and its practical application, and to thereby enable one of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

What is claimed is:

1. A method for collecting vibration data indicative of health of a machine, the method comprising: (a) attaching a vibration sensor to a measurement point on the machine; (b) collecting vibration data including a bin of vibration data that extends over a measurement time period having a begin time and an end time; (c) storing the vibration data in memory; (d) determining a first average amplitude of a first portion of the bin vibration data collected during a first time window that includes the begin time of the measurement time period; (e) determining a second average amplitude of a second portion of the bin of vibration data collected during a second time window that includes the end time of the measurement time period; (f) determining an amplitude difference between the first and second average amplitudes; (g) determining to retain or discard the bin of vibration data collected in step (b) based on comparison of the amplitude difference to one or more threshold levels; and (h) based on the determination of step (g) to discard the bin of vibration data, repeating steps (b) through (g) until it is determined in step (g) to retain the vibration data.

2. The method of claim **1**, wherein step (g) comprises deleting the vibration data collected in step (b) from the memory based on the amplitude difference being greater than a first threshold level.

3. The method of claim **2**, further comprising performing step (h) until the amplitude difference is less than the first threshold level, and then determining to retain the vibration data collected in step (b) in the memory.

4. The method of claim **1**, wherein step (g) comprises: (g1) prompting an operator to choose to retain or discard the vibration data collected in step (b) based on the amplitude difference being less than a first threshold level and greater than a second threshold level, wherein the second threshold level is less than the first threshold level; and (g2) retaining or discarding the vibration data collected in step (b) based on the choice of the user.

5. The method of claim **4**, wherein the prompting is accomplished with a visual prompt on a display screen.

6. The method of claim **1**, wherein the first time window begins at the begin time of the measurement time period and the second time window ends at the end time of the measurement time period.

7. The method of claim **1**, wherein a width of the first time window is no greater than one half of the measurement time period, and a width of the second time window is no greater than one half of the measurement time period.

8. The method of claim **1** wherein step (c) comprises storing the vibration data in memory of a vibration data collector or memory of an on-line vibration data collection system.

* * * * *